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Seabed Investigation on the Canadian Atlantic Continental Shelf

J. Vaughn Barrie and H.L. Snyder

Presented to the Canadian Petroleum Association Colloquium III: Petroleum Mapping and Surveys in the 80's, Banff, Alberta, October 14-16, 1981

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CENTRE FOR COLD OCEAN RESOURCES ENGINEERING
MEMORIAL UNIVERSITY OF NEWFOUNDLAND
ST. JOHN'S NEWFOUNDLAND A1B3X5 CANADA
TELEPHONE [redacted] (709) 737-8354

The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from government and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans. C-CORE's main concentration of research is on ice, its properties, detection and behaviour, on the interaction between oil and ice, and on seabed engineering.

ABSTRACT

New discoveries of hydrocarbons on the Grand Banks of Newfoundland and the potential reserves on the Labrador Shelf have greatly stimulated geophysical and marine surveying investigations of the Canadian Atlantic Shelf. This paper briefly reviews the approach and techniques required to perform a seabed survey and the related technological problems arising during such a survey.

Three aspects of a marine survey generally establish the past and present seabed environment; these are the seabed geomorphology, the physical nature of the substrate and the stability of the surficial sediments of the seabed. However, problems arise with the technical capabilities of the available survey equipment (e.g. side looking sonar systems and sub-bottom profilers). For example, the inability to locate accurately trailing transducers and hydrophones (contained in the 'fish') with respect to the operating vessel, restricts the accurate positioning of seabed features. This, coupled with wave-induced heave, depth limitations, distortion and operational complexity, inevitably results in these systems being used in a very narrow range of sea and operating conditions. Similarly it is difficult to measure directly the continuous modifications of the seabed at the bottom boundary layer.

The sedimentary material covering the Continental Shelf of Atlantic Canada is glacial-related in origin. The mechanical strength of these surficial sediments on some of the Labrador Banks and on Grand Bank is such that they are resistant to the penetration of the present generation of ship-deployed corers, and free-fall penetrometers. Nevertheless, grounding icebergs have penetrated and scoured these sediments to depths of several meters.

Recent technological developments that address some of the inadequacies in seabed investigations are described. The Hibernia region of northeastern Grand Bank is an example of an area where these developments have been incorporated with a coordinated survey approach to formulate a comprehensive seabed model.

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1. INTRODUCTION

Seabed investigations of the Canadian Atlantic Shelf have been given a fresh impetus by new discoveries of hydrocarbons on the Grand Banks of Newfoundland and the potential reserves on the Labrador Shelf. However, economical exploitation of these natural resources, through a variety of seabed installations will depend upon overcoming seabed geological and oceanographical problems. Hence, regional geological and geotechnical data of the seabed should be collected in a methodological manner reflecting initially the area of concern followed with site specific surveys.

Maritime studies of the regional surficial geology of the offshore, eastern Canadian Shelf have been underway for the past 15 years, both by industry and academic, but independently of each other. Initially, the work had been in the southern waters off Newfoundland and Nova Scotia but recently reconnaissance investigations have moved to the more northerly latitudes (Fig. 1). These academic research surveys have been generally coordinated through Canadian research organizations housed at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. The primary objective of these studies is to determine the stratigraphy, sedimentary character and geological history of specific areas from which models may be constructed and extrapolated to other areas. These studies, however, have not looked at the sediment dynamics of the shelf and virtually no consideration has been given to the geotechnical properties of shelf sediments outside of specific studies by the oil industry.

On the other hand, industry have undertaken detailed site surveys of drilling locations primarily to satisfy government regulations *(see; Offshore Exploratory Drilling, Procedures and Guidelines, 1980)*. Data collected, generally includes bathymetric, high resolution seismic, CDP seismics and side scan sonar surveys with a few sediment samples and bottom photographs of the seabed. The minimum area covered is approximately 2 square kilometers around the proposed wellsite. Many times operators extend this information base mainly to examine the ice scour density and distribution patterns.

Rarely have these two individualistic approaches been assimilated together to gain maximum information since the objective of both sources of data collection are, at first, too diverse. Only when production becomes a real possibility is coordination of the vastly different data bases of varying quality attempted and only then are the data gaps realized. This results in a new hurried program of data collection to evaluate the sediment stability of the seabed for engineering design by a 'catching up' method, resulting in poor scientific investigation, delays in engineering design and gross capital waste. Hence it is imperative to initiate at an early stage an organized regional surficial geological mapping program of the eastern Canadian Shelf. From this a firm basis can be provided for the eventual successful planning, cost effective execution and evaluation of site investigation surveys *(King, 1980)*. The objective of this paper is to outline some of the basic geological problems, delimit the technological gaps in undertaking these surveys and to formulate a guideline for future seabed investigations.

2. REGIONAL MARINE GEOLOGY

The basis of a comprehensive seabed investigation can be broken down into three broad but closely interrelated areas. Firstly, the bathymetry and surficial geology surveys of an area will define the morphology of the seabed and its possible long and short term evolutionary affinities. Secondly, the stratigraphic and geotechnical analyses of the soil substrate for an area will define the stability of both specific sites and of regional areas. Lastly, knowledge of whether the seabed is in equilibrium with its present hydrodynamic environment is critical to the interpretation of seabed morphology surficial sediment stability and subsequently to the areas' geotechnical characteristics.

2.1 Seabed Geomorphology

Many geomorphological aspects of the seabed on the shelf proper are significant to offshore engineering studies. Such features are formed by varied processes and can be both geological hazards in the engineering sense and also geological aids in some cases, eg., land forms now submarine, exceptional morphological features and sedimentary bedforms both active and inactive.

Nearly the whole of the eastern Canadian Continental Shelf was formerly glaciated. The typical shelf is characterized by a surficially 'rough' inner shelf which is an offshore continuation of the land, bordered by a relatively deep marginal channel and in many areas transverse depressions, followed offshore by elongated, flat-topped banks with intervening saddles to the continental slope (Fig. 1). The morphology of such shelves has been considered glacial in origin (by processes of glacial scour *(Holtedal, 1956)*) but recent evidence on the Scotian Shelf indicates the shelf is bedrock controlled *(King, 1980)* representing cuestas and mesas with adjacent lowland areas. Upon this basic bedrock morphology, glaciation and periglacial activity have since modified the banks and deposited glacially derived sediments over the entire shelf. It was probably during this period that the boulder beds (boulder pavements) were laid which are now proving to be a major problem for drilling operations, in the more northern areas.

At the end of the Pleistocene in Canada, areas of the eastern Canadian Shelf were subaerially exposed and drainage systems were developed draining to the shelf edge, many being overdeepened by glacial erosion *(King, 1980)*. These have since been filled and can be clearly seen in the bathymetric and seismic profiles. The possibility exists of using these channels to route pipelines and cables over an otherwise rough bedrock and gravel terrain *(King, 1980)*. Similarly, fjord-like features *(Sheppard, 1931; King, 1980)* along the Laurentian Channel and in areas immediately offshore from Newfoundland were created during the same period and are now fully submarine.

During this period of low sea level stands wave cut terraces were formed in many areas of the eastern Canadian Shelf. These features relate to specific time periods of relative stability in sealevel rise associated with the Holocene transgression. Hydrodynamic bedform features were developed in the shallower waters during periods of stronger seabed boundary layer flow. This redistribution of material in some areas of the inner shelf left areas of exposed or nearly exposed bedrock. Originally these areas were covered with glacial till but the eroding capability of the transgressing sea on the

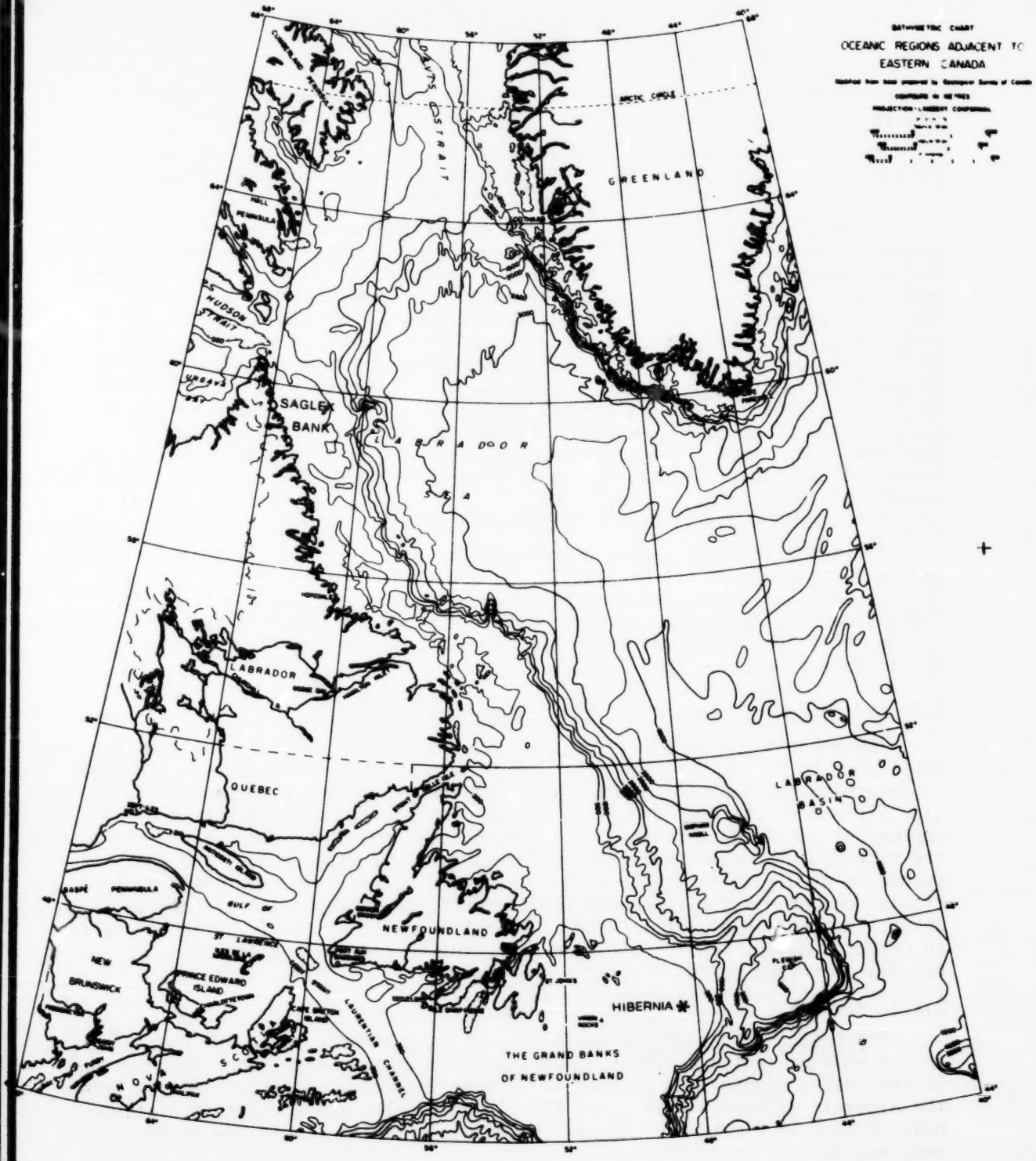

Figure 1. The Canadian Atlantic Continental Shelf

greater slopes removed this material leaving a bedrock surface with coarse gravel confined to the depressions *(King, 1980)*.

Two geological features that are physical evidence of hazards are iceberg furrows and pockmarks. In both cases the morphological evidence may represent both past (relict) and modern processes.

Iceberg scours (furrows), the term generally used for the interaction process, are formed by the keel of an iceberg as it interacts on the sea bottom under the influence of currents, strong winds, tides or pressure from other ice. Both modern and relict iceberg scours occur along the entire length of the eastern Canadian Shelf *(Harris, 1974; Harris and Jollymore, 1974; King, 1976; Gustajtis, 1979; Lewis et. al., 1979; Barrie, 1980; Fader and King, 1981; Lewis and Barrie, 1981)*. Such scours can vary from a maximum of 17 m in depth of penetration *(Barrie, 1980)*, to over 200 meters in width *(Harris, 1974)* and extend for many kilometres in length. They have been recorded in water depths of up to 400 meters. This is the one unique feature that dominates the seabed of the eastern Canadian Shelf from the Grand Bank northwards and is potentially the most hazardous to offshore development. A typical example of the density and morphology of iceberg scouring is shown for 30 km_2 region of southern Saglek Bank (Fig. 1) in Figure 2.

Pockmarks are cone shaped depressions occurring in unconsolidated fine sediment, commonly on the Scotian Shelf, but also do occur elsewhere on the Continental Shelf; they are thought to be formed by gas escaping from underlying sediments *(Josenhans et al., 1978)*. Many of the pockmark features seen on the shelf are relict and therefore, cannot be considered a major hazard to offshore production facilities.

2.2 Hydrodynamic Stability of the Sediments

The genesis and stability of the seabed sediments can be modelled assuming the seabed to be unaffected by the superimposed hydrodynamic regime. In order to determine the sediment stability at the benthic boundary layer and its significance on the hydrodynamically static seabed stability model, two approaches can be undertaken; one is to directly and comprehensively measure the hydrodynamic regime near the seabed (normally 1 meter above) and the second is by direct inference from sedimentary seabed bedforms formed by particular components and thresholds of the superimposed hydrodynamic regime. In doing a seabed survey, it is these latter features that the investigator needs to detect and map. The most common hydrodynamic sedimentary bedforms are briefly described below.

2.2.1 Ripples

Ripples, the smallest of bedforms, can only be seen on seabed photography or can be represented as areas of strong reflection on side scan sonograms due to the seabed roughness. An example of wave-induced ripples can be seen from the Hibernia discovery area (Fig. 3). These ripples are short term features being erased in a matter of months by benthic activity *(Lewis and Barrie, 1981; Amos and Barrie, 1980)*.

2.2.2 Megaripples

As the current velocity increases to approximately 60-70 cm/sec. *(Dalyrymple et al., 1978)*, increasing the boundary shear stress, megaripples can

SIDE SCAN MOSAIC, SAGLEK BANK
CSS HUDSON 79-019

Figure 2

Figure 3. Wave-induced ripples at 80 metres water depth near Hibernia discovery area, Grand Bank

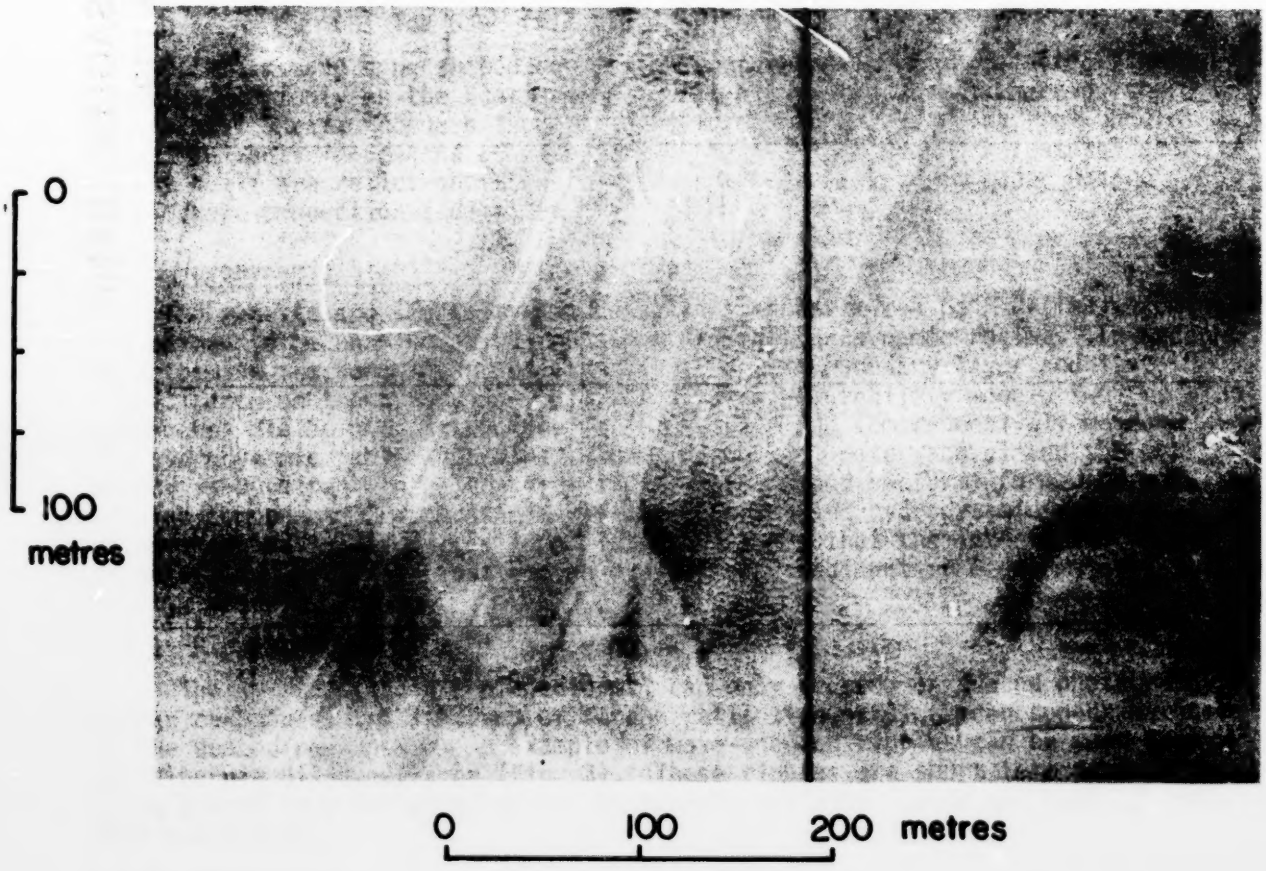

Figure 4. Arcuate sand waves on Grand Bank at 80 metres water depth. Notice the superimposed megaripples on the stoss side of the sand waves, a common feature.

be formed. Megaripples are similar in shape to ripples and often have small ripples superimposed on their backs. They range in length from 60 cm to several meters and are short term response features, only lasting a very few years *(Swift, et al. 1979)*. In the Hibernia discovery area large fields of megaripples exist and their age can be seen to be less than 20 years when compared to fishing otter board trawl marks seen on high-resolution sonograms.

2.2.3 Sand Waves

The largest hydrodynamically formed bedform are sand waves or giant ripples. These are formed and maintained in velocities greater than 50 cm/sec *(Dalyrymple et al. 1978)* and are long term response features *(Swift et al., 1979)*. Therefore sand waves seen on sonograms of the eastern Canadian Shelf may be relict. For example the sand waves seen in Figure 4 occur in 80 metres water depth on the northeastern Grand Banks and could be both modern or relict. Until current measurements are completed the time of their genesis cannot be determined.

2.2.4 Sand Ribbons

Sand ribbons are linear bedforms on sandy to gravelly shelf bottoms. They can be as long as 15 km and up to 200 m broad with little height (less than 1 meter). These features are common transgressive features usually occurring in sediment starved areas where surface current velocity exceeds 1 m/sec *(Kenyon, 1970)*. Modern sand ribbons have been described by Belderson and Stride *(1969)*. The sand waves and megaripples in Figure 4 are superimposed on the crest of a sand ribbon.

2.2.5 Megaflutes

Flute marks are small tongue - to triangular - shaped depressions on the surface of the seabed. They are formed by bottom current erosion of muddy sea bottoms on the lee side of seabed obstacles. Megaflutes are 100 to 200 m long and flare to widths of 50 to 150 m *(King, 1980)*. The bottom current shear stress required to cause erosion of these large flutes is not known.

2.3 Geotechnical Characteristics

The characteristics of the regional surficial geology of the eastern Canadian Atlantic Shelf along with the associated geologic features have been briefly discussed above. Geotechnical properties of marine sediments reflect and at the same time indicate the equilibrium state of the seabed with its external physical environment and its internal response to gravity. Hence geotechnical analyses are a prerequisite and should be an integral part of any overall study. Characteristics such as the liquid and plastic limit, plasticity index, sediment strength, pore pressures, etc. should be necessarily analysed and these results used to complement the regional geology survey. From this a comprehensive marine geological model of the area can be derived. A more detailed discussion other than the mention above of the geotechnical properties is beyond the scope of this paper and it is a field of research that requires immediate attention due to the dearth of geotechnical information that exists on the eastern Canadian Shelf.

3. FIELD INVESTIGATION METHODS

3.1 Remote Sensing

Surficial geological interpretation and the resultant maps are based on remote sensing techniques using an acoustic source. The geologist needs to understand the substrate and the morphology of the seabed both over the region and in much greater detail for the specific area in question. To enable this to be done manufacturers have developed acoustical systems that fall into four main categories:

1) echo sounders for water depth and seabed morphology,

2) shallow seismics to resolve the upper few hundred metres of bedrock and surficial overburden,

3) high resolution seismics for detailed examination of the upper few metres of surficial material in cross section and

4) side scan sonar for examination of the seabed, surficial sediment and morphological character.

The objective of a survey is to investigate the character of the sea floor, thus exact positioning is critical and because of the constant motion of the sea, positioning information must be derived from indirect electronic measurements. Today this is possible for a ship but not for a trailing acoustic hydrophone. In order to get the best information, the fish for high resolution seismic systems and side scan sonars are towed well behind and below the research vessel to minimize distortion due to heave heave. Relative position accuracy of the returning seismic information is in the order ot 10's of meters. In areas of critical features such as iceberg scours, navigational errors of 50 - 100 meters and motion changes of a few meters can make any scientific interpretation futile and meaningless.

Added to this problem is the penetration rate, resolution and presentation of data collected by various makes of equipment. Survey investigations of the same site by similar equipment from different manufacturers, more often than not give markedly differing results. This is most apparent with side scan sonar. Many of the differences are due to distortion as a result of slant range ambiguity and variation in the speed of the surveying vessel. Also presentation of the data is highly dependent on the operators ability to understand what one is seeing on the graphic recorder so as to achieve quality control.

Many of these difficulties are presently being addressed, by both industry and government. The Huntec DTS high resolution seismic surveying system is compensated for vertical movement of the fish due to winding in or paying out cable, or movement caused by heave of the tow point in heavy weather *(Hutchins, 1980)*. An example of two data sets collected simultaneously, one heave compensated the other not, is shown in Figure 5.

This same design will be used as the basis for a further joint research and development programme, Project Seabed II, involving Huntec ('70) Ltd. and several agencies of the Federal Government. Some highlights of this project are track recovery or positioning of the tow fish relative to the vessel and inclusion of side scan sonar as part of the system. Specifications of some of these ideas are presented by Hutchins *(1980)*.

Figure 5. An example of two sub-bottom profiles taken on the Grand Banks simultaneously. Profile (a) is an O.R.E. 3.5 sub-bottom profile without heave compensation and profile (b) is a Huntec DTS high resolution seismic profile with heave compensation

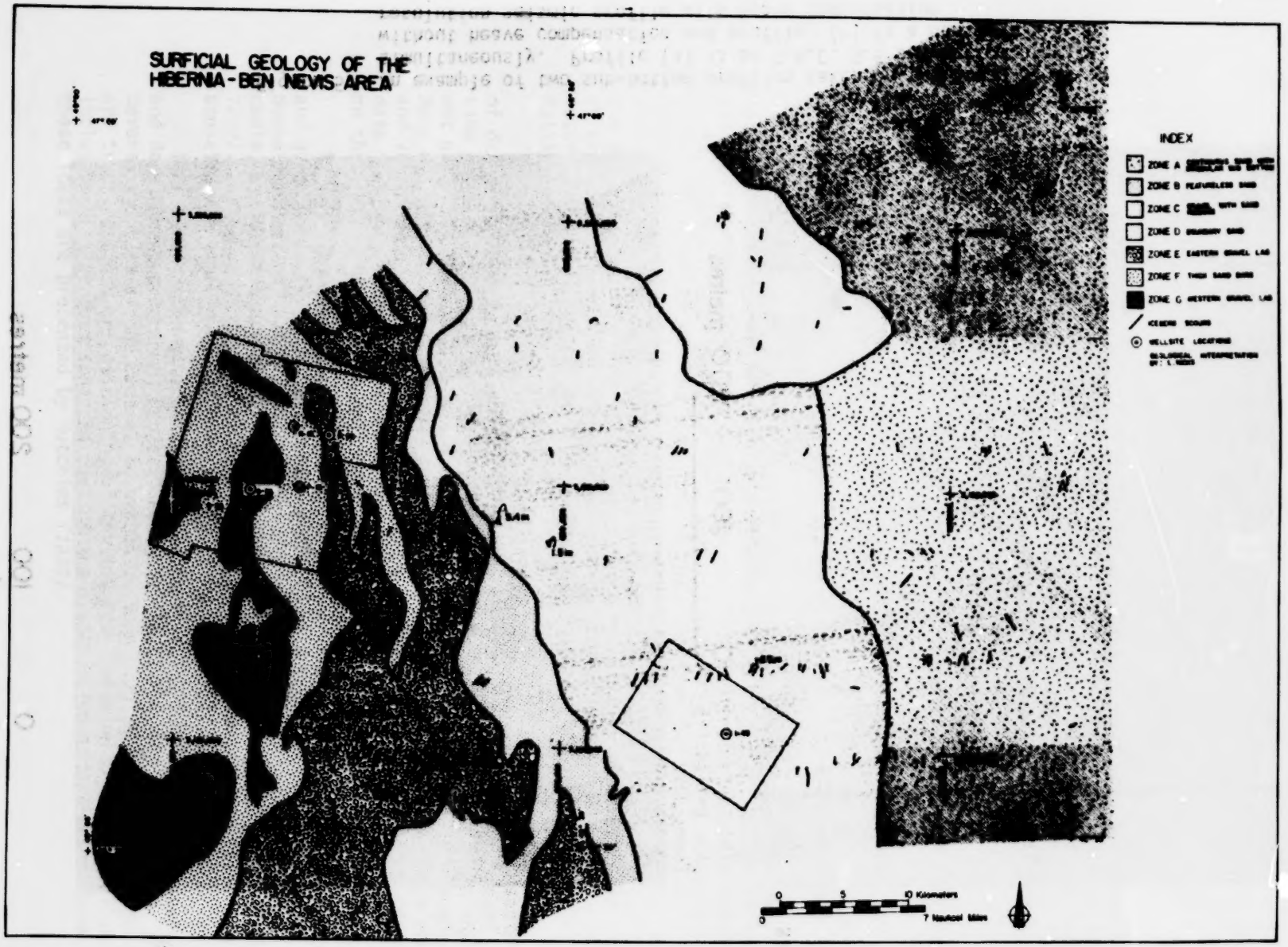

Figure 6. Surface sediment facies in the Hibernia-Ben Nevis research area.

Side scan sonar has become a critical tool for offshore site investigations. Present side scan technology is working towards true mapping systems or spatially correct records of the sea bottom which will greatly facilitate the compilation of mosaics. Both EG and G, Geometrics and Klein have such systems available now with three channels. These new systems do not overcome the fundamental limitation of side scan; i.e. that resolution along the track is inversely proportional to range and range ambiguities limit the pulse repetition rate *(Hutchins, 1980)*. A potential new development is synthetic aperature multi-beam side scan sonars fitted with motion sensors *(Hutchins, 1980)*. Ideally this would be housed in a fish with a high resolution seismic system and narrow beam echo sounder all of which is heave compensated and can be positioned.

3.2 Seabed Sampling and Photography

Seabed sampling and photography are the means of groundtruthing the high resolution seismic and side scan sonar data. A geological interpretation would be tenuous if not backed by stratigraphic, sediment and geotechnical analyses of cores and surficial grab-samples. With a knowledge of the regional geology from the desired seismic surveys and the detailed geological and geotechnical interpretation from the sampling program an overall comprehensive model can be developed. Subsequently, if an indepth analysis of a proposed wellsite area is required the sites for the cores of the top few meters of the substrate along with the surficial samples and bottom photographs can be predetermined from the already determined overall model, saving considerable time and expense.

There are various types of corers including the gravity, piston, vibra, and box corer. Similarily, there are many kinds of sampling devices, the most common of which are the Van Veen and the shipek grab. Various types of dredges are also used for specialized bottom sampling.

Due to the glacial origin of the eastern Canadian Shelf, the near surface semiconsolidated Tertiary bedrock and the exposure of the shallow bank tops to incoming swell, the surficial sedimentary units in many areas have a very high shear stength. Using a standard corer, these sediments cannot be penetrated. Similarily, the toughness of these sediments restrict penetration of free fall penetrometers *(Chari, et al., 1979; Chari and Abdel-Gawad, 1981)*. Expensive geotechnical coring drills requiring specialized tender vessels or drill platforms, can operate in these soils but for an initial seabed investigation such an expense is unrealistic.

An example of a new type of inexpensive mobile seabed coring device to be used in these soil types is the C-CORE coring drill. The drill is free standing and is connected to the vessel by power and control cables. The drill is made of a standard size H core barrel which takes a 61 mm core. The core barrel may be fitted with a diamond or tungsten carbide bit as required. This seabed corer, which has a core capacity of 3 m is at present undergoing trials which have so far proved encouragingly very successful and is capable of sampling in an area of rough rock infill.

3.3 Sediment Dynamics

The geophysical survey accompanied with sampling should delimit the hydrodynamic sedimentary bedforms described earlier. From its interpretation, a basic hydrodynamic model can be hypothesised. The question that still remains at this point is, are the sedimentary bedforms in equilibrium with the present

hydrodynamic regime or are they relict? To answer this direct measurement of current threshold velocities near the seabed are required.

Engineers and geologists interested in the dynamics of the water/seabed interface (benthic boundary layer) need to profile the current regime throughout, and at the very least, the first meter above the seabed. Both unidirectional and oscillatory motion needs to be measured. This differentiates the wave component from the residual current and tide component. The standard method for measurement of current shear velocity at the seabed has been accomplished by putting a current meter with a savonius rotor or impellor one meter above the seabed. The current profile to the seabed is then estimated. However there are problems in its exact determination *(Bowden, 1973; Dyer, 1971)* and in addition savonius rotors and impellors are adversely affected by oscillatory motion *(Hammond & Collins, 1979)*.

A device being developed to measure sediment shear stress and transport is "RALPH", which is designed and built at the Atlantic Geoscience Centre of the Bedford Institute of Oceanography *(Heffler, 1979)*. RALPH is a code name for a remote controlled sediment dynamics monitor which encorporates a multiparmater sensing array on a bottom mounted tripod, controlled by an inbuilt microcomputer. The unit at present has a two component electromagnetic current meter, 1 meter above the bed, an upward looking sonar to record the wave regime, a turbidity meter to measure turbidity, a time lapse camera to record sediment movement as well as salinity and temperature probes. New innovations presently being added to RALPH at C-CORE are electro-chemical current meters (anamometers with a response time of approximately 1 sec. to measure currents velocities of less than 0.1 cm/sec.) Eight of these are situated throughout the bottom one meter of RALPH; they are presently being tested in a field situation.

4. HIBERNIA SEDIMENTS PROGRAM - A CASE STUDY

The Hibernia discovery area, located in 80 meters of water on the northeast margin of the Grand Bank is clearly vulnerable to the iceberg scouring threat and to sediment transport. Until recently little was known of the origin of the surficial geological units and the degree of which seabed sediments are mobilized and redistributed by the hydrodynamic processes. As the possibility of production looms at Hibernia, original research into seabed problems will be of widespread scientific and engineering interest.

During 1980 a seabed investigation was initiated in the Hibernia discovery area which can be broken down into four constituent parts:

1) extending on established regional geological mapping program onto the northern Grand Banks *(Fader and King, 1981)*;

2) detailed mapping of the surficial geology in the Hibernia area *(Lewis and Barrie, 1981)* to interpret its evolution;

3) modelling current shear and sediment transport;

4) evaluating iceberg scours (iceberg disturbed seabed) and prediction of iceberg flux over the entire area.

Known collectively as the Hibernia Sediments Program this work is led by scientists from the Atlantic Geoscience Centre at the Bedford Institute of Oceanography and the Centre for Cold Ocean Resources Engineering (C-CORE) of Memorial University of Newfoundland in cooperation with Mobil Oil Canada Ltd.

The purpose of this Hibernia program was to address the areas of research outlined above by coordinating the information from industrial well-site site investigations, regional geological mapping by the Geological Survey of Canada and specific scientific and engineering studies into one major study. Specialized scientific cruises were undertaken to complete the data gap between these various scientific and engineering programs. Two cruises on the Mobil Charter vessel POLARIS V *(Amos and Barrie, 1980)* and a further cruise of the Canadian Hydrographic Vessel BAFFIN *(Lewis 1981)* procured the necessary geophysical and sample information to complete the seabed investigation. In addition a seabed current meter program was carried out through 1980 and the program also benefited from three borehole reports by Geocon (75) Ltd.

Until the Hibernia Sediments Program was undertaken only the Hibernia, Ben Nevis and Trave/White Rose wellsite surveys had been completed. None of the earlier data from these wellsites was recorded on analogue tape and the sub-bottom profiler was not heave compensated. Upon this data set and the subsequent side scan sonar lines between Hibernia and Trave/White Rose, no geological interpretation of iceberg scour or definition sediment stability could be made. The program that followed then set up a larger site investigation area including systematic geophysical survey lines, bottom sampling with photography and regional survey lines to tie the Hibernia area into the Grand Bank geological framework. The result is a detailed surficial geological map (Figure 5) of the Hibernia discovery area which directly ties into the regional map of northern Grand Banks *(Fader and King, 1981)*.

5. SUMMARY CONCLUSIONS

Regional maps from geological survey programs provide a wealth of information on the occurrence, distribution, interrelationships and character of geological attributes of the seabed *(King, 1980)*. Upon this background site specific studies can be planned, carried out and interpreted in their proper geological perspective.

During the execution stage of a site survey, geological input is necessary to assess data quality, to make preliminary interpretations and to recognize anomalous or unanticipated geological conditions which calls for a change in approach *(King, 1980)*. Many of the diagnostic hydrodynamic bedforms, described previously, are not always easily recognizable and therefore may not be properly recorded by the operator of the side scan sonar. Although initial identification of a dynamic bottom may not be of concern during exploration drilling, when production is a reality and definition of seabed stability is required, repeat side scan sonar mosaics over sedimentary bedforms can give the investigating geologist or engineer a record of bedform migration. If the data was not originally taken properly, as is so often the case (i.e. the records have far too much distortion, gains on the playback were constantly changed, etc.), it will be useless for further repeatative mapping and a new program might be too late. It is the responsibility of the contractor to ensure the quality of data to be achieved. A geologists' input then at the planning and execution stage is important.

Also consideration should be given to the placement of near bottom current meters and systems used, as a change in sediment facies will change the boundary layer characteristics greatly. To record these differences, placement and capability of the measuring systems will make the difference between good quality

data and the questionable data. In all parts of a seabed investigation the operator through its various contractors should keep abreast of technological developments and an awareness of present research and development.

The regional geological information base at best is fragmentary and incomplete although it defines the lateral geological environment. A defined wellsite survey is far too small to identify the geological processes that have and are presently taking place. As the engineers are primarily interested in the stability of the seabed and substrate neither survey approach will give the definitions necessary, but by incorporating the relating both approaches with a systematic coverage of the full production area in question, a seabed model including the geotechnical characteristics, surficial sediment stability and geological hazards can be achieved.

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